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RELATIONSHIPS OF MIDDLE SILURIAN STRATA IN OHIO AND WEST VIRGINIA[1]

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ABSTRACT

The Estill, Bisher, Lilley, and Peebles Formations crop out in Adams and Highland Counties, Ohio. All these units can be traced several miles eastward into the subsurface of the Appalachian Basin. Farther east, the Peebles and Lilley strata lose their distinctive lithology and become part of subsurface beds identified as Lockport by previous investigators. The Lockport beds intertongue with carbonates of the McKenzie Formation in eastern Ohio and western West Virginia.

The "Clinton shale" of the driller shows a three-fold division in the subsurface of central Ohio: 1) upper dolomitic shales, 2) intermediate silty or arenaceous carbonates, and 3) lower green and brown clay shales. The upper and middle units can be traced from central Ohio southwestward into the Bisher, and the lower unit into the Estill Shale of southern Ohio. Eastward, near the Ohio-West Virginia boundary, the middle unit of the "Clinton shale" shows a facies relationship with the Keefer Sandstone. The lower unit of the "Clinton shale" can be traced eastward into the upper half of the Rose Hill Formation in West Virginia.

INTRODUCTION

This report is the second part of an extensive study of the Silurian strata in Ohio and neighboring states (Horvath, 1964, 1967). The primary purpose of the investigation was to determine whether rock units named for surface exposures in Adams and Highland Counties, Ohio (fig. 1), were identifiable in the subsurface. A secondary goal was the determination of the geographic extent of the identifiable units and their stratigraphic equivalents in central and eastern Ohio and in West Virginia. Data used in preparation of this study included gamma-ray neutron logs and drill cuttings from approximately 74 drill holes (fig. 2 and table 1). In addition, two strategic cores through the Silurian sequence in Pike County, Ohio (fig. 1), were examined, and descriptions of measured sections from various geological survey publications or unpublished theses were consulted. Finally, the exposed Silurian rock units in Adams and Highland Counties were studied and sampled for comparison with core and drill cuttings.

PREVIOUS INVESTIGATIONS

Orton's Silurian studies in southern Ohio were published in 1871. His work was followed by the field investigations of Foerste (1896–1935), which spanned a 40-year interval. These two geologists named and described most of the currently recognized units. More recently, Bowman (1956), Kaufmann (1964), and Rexroad and others (1965) have investigated the Silurian in Ohio.

On the eastern flank of the Appalachian Basin, Swartz (1923) correlated the Silurian formations of Maryland with the standard section of New York State

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and Woodward (1941) summarized the Silurian strata of West Virginia. Travis (1962) contributed petrographic studies of the McKenzie Formation, and Folk

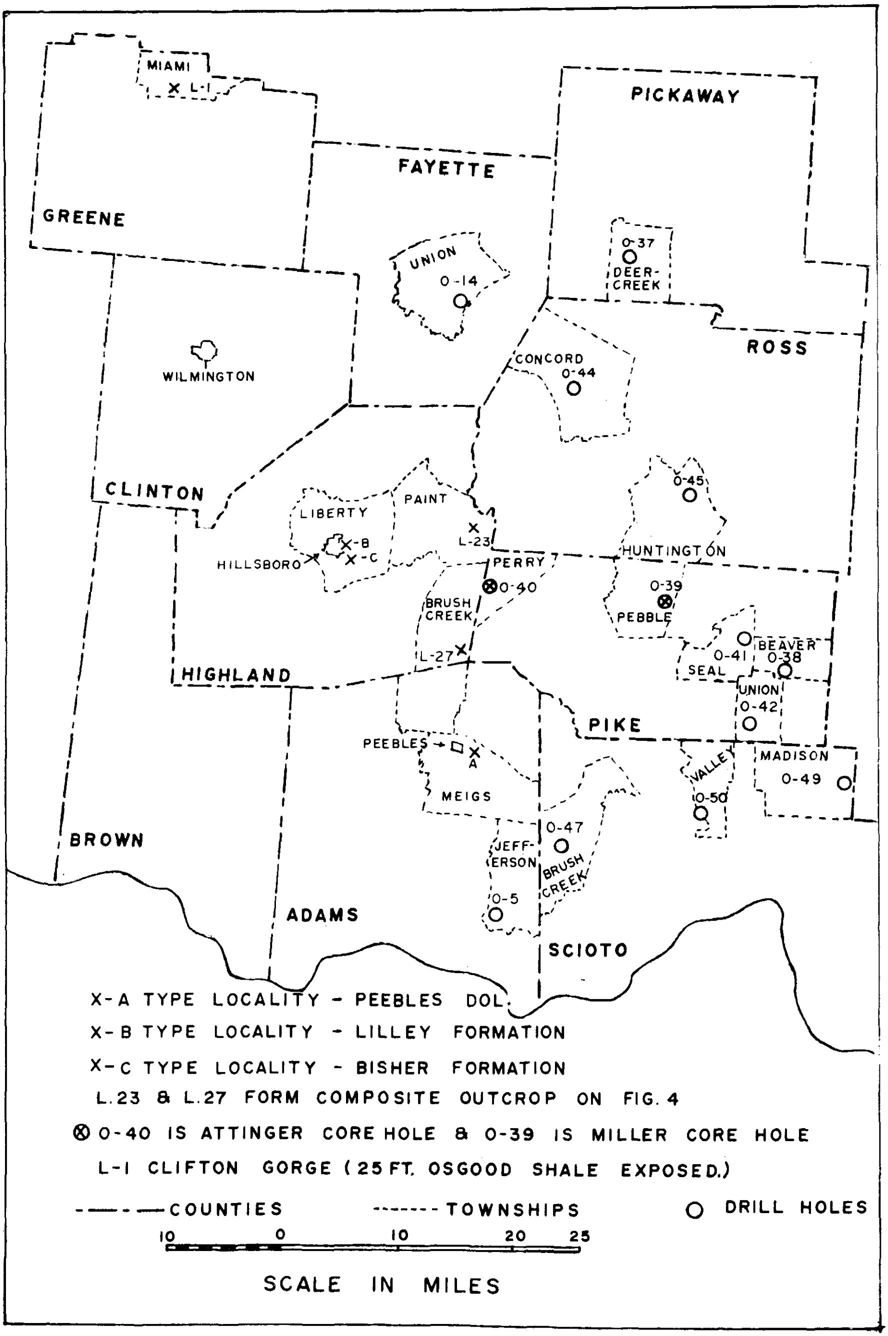

FIGURE 1. Location map of main area showing the key outcrops, core holes, and nearby drill holes.

(1962) has reconstructed the paleoenvironment of eastern West Virginia during the Silurian Period from petrographic investigations. Fundamental to an understanding of the regional paleogeography in the central and northern Appalachian Basin are subsurface studies by Rittenhouse (1949) and Freeman (1951).

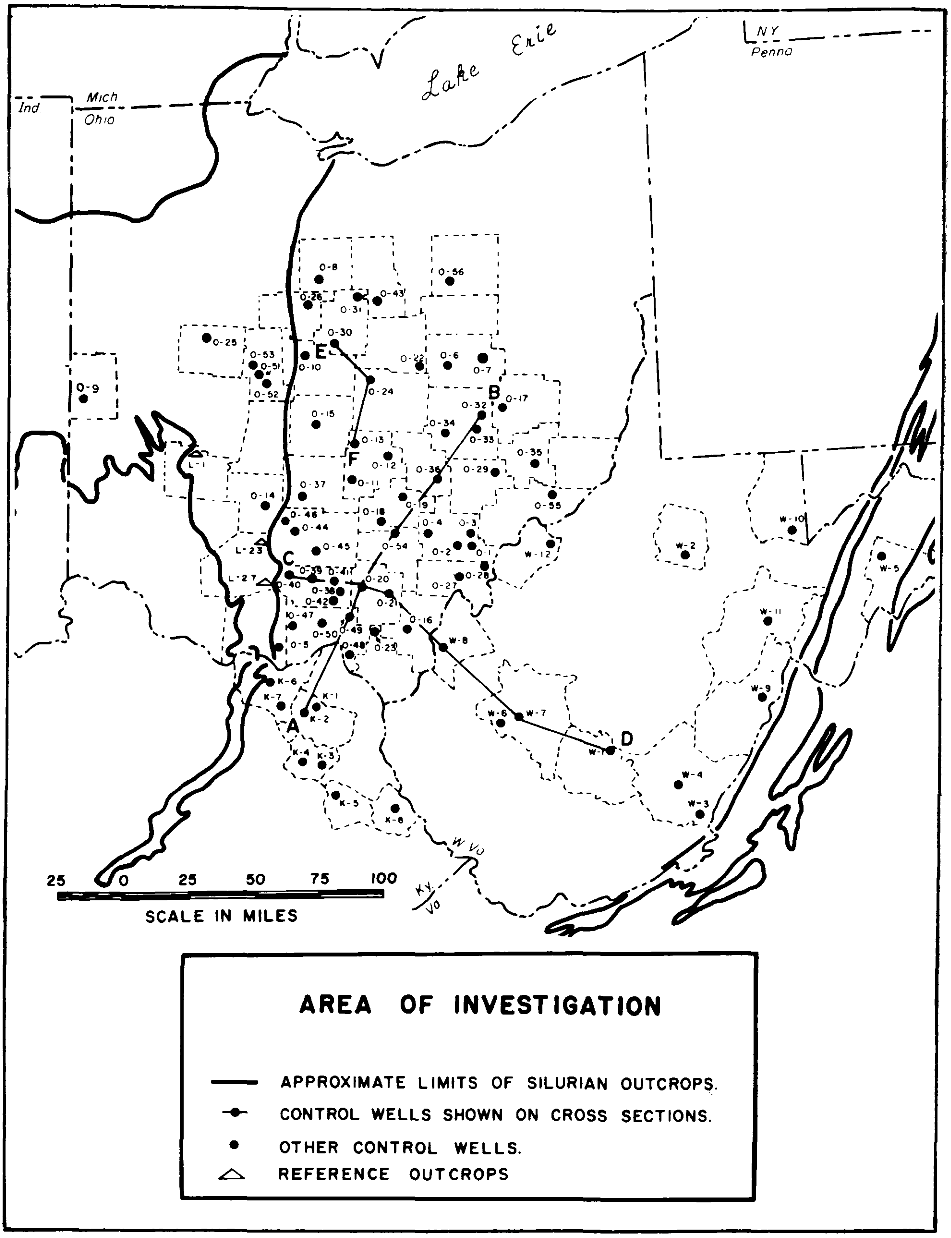

FIGURE 2. Area of investigation showing location of all drill holes and cores supplying information for this report; also shown are lines of cross-section for Figures 4, 5, & 6.

STRATIGRAPHY

Middle Silurian Strata in Ohio

In Adams, Highland, and adjacent counties in southern Ohio, the following Silurian units crop out:

Peebles Dolomite
Lilley Formation
Bisher Formation
Estill Shale

These units are described below.

Estill Shale—The Estill Clay Member of the Alger was named by Foerste (1906, p. 59) for 56 feet of blue shale exposed near Estill Springs, north of Irvine, Estill County, Kentucky. Rexroad and others (1965) changed the name to Estill Shale and consider the unit to be of formational rank because of its thickness, distinctive lithology, and clearly marked boundaries.

In Adams County, Ohio, the Estill rests on limestones belonging to the Dayton Member of the Noland Formation and is overlain by the Bisher Formation. The Estill-Bisher contact is distinct, but conformable. According to Rexroad and others (1965, p. 32) the Estill lies unconformably on the Noland. Beds of green shale with some interbeds of brown and maroon shales comprise the bulk

TABLE 1
Names and locations of drill holes supplying subsurface data

Map Number	Name	Location	State Permit or Sample Number
K-1	R. Thomas, Simmons No. 1	S. 11, Twp. W, R. 78, Carter Co., Kentucky	----
K-2	United Fuel, Stamper No. 1	Coord., 3-V-77, Carter Co., Kentucky	----
K-3	Inland Gas, Fraley No. 1	Coord., 24-T-77, Elliott Co., Kentucky	----
K-4	United Fuel, Pennington No. 1	Coord., 21-T-76, Elliott Co., Kentucky	----
K-5	Ashland Oil, Williams No. 8	Coord., 19-R-79, Johnson Co., Kentucky	----
K-6	W. E. Lang, Clark	Coord., 18-Y-74, Lewis Co., Kentucky	----
K-7	United Fuel, Shepherd No. 1	Lewis County, Kentucky	----
K-8	United Fuel, James No. 1	Coord., 19-Q-84, Martin Co., Kentucky	----
O-1	Flagg Co., Chapman No. 1	S. 29, Carthage Twp., Athens Co., Ohio	S-1089
O-2	Midland Explor., Burson No. 1	S. 28, Rome Twp., Athens Co., Ohio	P-1395
O-3	Real Corp., Skinner No. 1	S. 22, Rome Twp., Athens Co., Ohio	S-905
O-4	El Paso Nat. Gas, Kisor No. 1	S. 16, Waterloo Twp., Athens Co., Ohio	S-1077
O-5	Cabot Corp. et al., Bailey No. 1	Jefferson Twp., Adams Co., Ohio	S-2030
O-6	Nat. Assoc. Pet., Gilmore	S. 7, Bedford Twp., Coshocton Co., Ohio	S-761
O-7	Roberson et al., Geib	L-15, Keene Twp., Coshocton Co., Ohio	S-694
O-8	Plains Explor., Blicke	S. 22, Bucyrus Twp., Crawford Co., Ohio	S-1122
O-9	American Aggregates Co. (core)	Ft. Jefferson Quarry, Darke Co., Ohio	----
O-10	J. Adams, Humphreys No. 1	L-7W, Radnor Twp., Delaware Co., Ohio	S-1103
O-11	Lancaster Nat. Gas, Brown No. 1	S. 30, Amanda Twp., Fairfield Co., Ohio	S-438
O-12	Kubat, Ruff No. 1	S. 30, Richland Twp., Fairfield Co., Ohio	S-945
O-13	Graber, Fisher No. 1	S. 8, Violet Twp., Fairfield Co., Ohio	S-843
O-14	Kewanee, Hopkins No. 1	MS-663, Union Twp., Fayette Co., Ohio	S-750
O-15	Battelle Mem. Inst., Battelle No. 1	— Columbus (city), Franklin Co., Ohio	S-630
O-16	Waggoner, Gills No. 1	S. 28, Perry Twp., Gallia Co., Ohio	S-915
O-17	Lake Shore Pipeline, Marshall No. 1	S. 15, Adams Twp., Guernsey Co., Ohio	S-925
O-18	Kewanee, Amerine No. 1	S. 33, Benton Twp., Hocking Co., Ohio	S-738
O-19	Rixleben, Adcock No. 1	S. 34, Green Twp., Hocking Co., Ohio	S-909
O-20	Continental, Grover No. 1	S. 19, Liberty Twp., Jackson Co., Ohio	S-1023
O-21	Kewanee, Buckeye No. 2	S. 23, Milton Twp., Jackson Co., Ohio	S-759
O-22	Nat. Assoc. Pet., Wilt No. 1	S. 21, Jackson Twp., Knox Co., Ohio	S-783
O-23	Weed & Assoc., Cambria Clay No. 1	S. 11, Washington Twp., Lawrence Co., Ohio	S-900
O-24	Patten, Martin No. 1	L-2, Hartford Twp., Licking Co., Ohio	S-855
O-25	Ohio Oil, Johns No. 1	MS-9930, McArthur Twp., Logan Co., Ohio	S-192
O-26	J. Adams, Key No. 1	S. 3, Claridon Twp., Marion Co., Ohio	S-1044

TABLE 1—(*Continued*)

Map Number	Name	Location	State Permit or Sample Number
O–27	Ohio Fuel Gas, Windom No. 1	S. 1-W, Chester Twp., Meigs Co., Ohio	S-827
O–28	Sinclair, Longworth No. 1	L–23, Olive Twp., Meigs Co., Ohio	S–253
O–29	Morrow Co., Murray No. 1	S. 12, Meigsville Twp., Morgan Co., Ohio	S–210
O–30	Brasel & Brasel, Riggs No. 1	L–16, Bennington Twp., Morrow Co., Ohio	S–1091
O–31	Pan American, Windbigler No. 1	S. 18, Troy Twp., Morrow Co., Ohio	S–1033
O–32	Kewanee, Lake No. 1	S. 24, Highland Twp., Muskingum Co., Ohio	S–787
O–33	Kewanee, Mikolojcik No. 1	S. 19, Perry Twp., Muskingum Co., Ohio	S–838
O–34	Wehmeyer, Wilkins No. 1	S. 17, Springfield Twp., Muskingum Co., Ohio	S–779
O–35	Maddox & Johnston, Burkhart No. 1	S. 10, Enoch Twp., Noble Co., Ohio	S–639
O–36	Ridgedale Oil & Gas, Vargo No. 1	S. 1, Pleasant Twp., Perry Co., Ohio	S–921
O–37	McMahon et al, Dunlap No. 1	VMS–4016, Deercreek Twp., Pickaway Co., Ohio	S–1178
O–38	Continental, Quinsell No. 1	S. 5, Beaver Twp., Pike Co., Ohio	S–1066
O–39	Continental, Miller No. 1	— Pebble Twp., Pike Co., Ohio	P–22
O–40	Continental, Attinger No. 1	— Perry Twp., Pike Co., Ohio	P–21
O–41	Continental, Anderson No. 1	S. 13, Seal Twp., Pike Co., Ohio	S–1070
O–42	Southern Triangle, Woodell No. 1	S. 26, Union Twp., Pike Co., Ohio	S–1121
O–43	Pan American, Mertler	S. 35, Troy Twp., Richland Co., Ohio	S–1095
O–44	Kissling Bros., Perie No. 1	L–407, Concord Twp., Ross Co., Ohio	S–153
O–45	Continental, Wenzel No. 1	VMS–4642, Huntington Twp., Ross Co., Ohio	S–1072
O–46	Crest Oil Co., Clark No. 1	VMS Concord Twp., Ross Co., Ohio	S–1454
O–47	Continental, Jones No. 1	VMS–14887, Brush Creek Twp., Scioto Co., Ohio	S–1067
O–48	Smith & Dow Chem., Rose No. 1	L–82, Green Twp., Scioto Co., Ohio	S–437
O–49	Continental, Dever No. 1	S. 20E, Madison Twp., Scioto Co., Ohio	S–1045
O–50	Continental, Shisler No. 1	S. 5-S, Valley Twp., Scioto Co., Ohio	S–1068
O–51	J. Adams, Holycross No. 1	VMS–3742, Allen Twp., Union Co., Ohio	S–1011
O–52	J. Adams, Snyder No. 1	VMS–15310, Darby Twp., Union Co., Ohio	S–1010
O–53	J. Adams, Carreker No. 1	VMS–12400, Liberty Twp., Union Co., Ohio	S–1009
O–54	Arnold Oil, Hewitt No. 1	S. 7, Swan Twp., Vinton Co., Ohio	S–640
O–55	Great Lakes Carbon, Scott No. 1	S. 20, Liberty Twp., Washington Co., Ohio	S–633
O–56	Kubat, Sanger	S. 25, Plain Twp., Wayne Co., Ohio	S–914
W–1	Shell Oil, Foulke No. 1	Nuttall Twp., Fayette Co., W. Virginia	123
W–2	Hope Nat. Gas, Gribble #8517	Grant Twp., Harrison Co., W. Virginia	79
W–3	United Fuel, Damron No. 1	White Sulphur Twp., Greenbrier Co., W. Va.	13
W–4	Texas Co., Dean No. 1	Williamsburg Twp., Greenbrier Co., W. Va.	2
W–5	Baker & Harshberger, Williams No. 1	Moorefield Twp., Hardy Co., W. Vriginia	1
W–6	Benedum-Trees, Hill #1668	Jefferson Twp., Kanawha Co., W. Virginia	166
W–7	Columbia Carbon, Campb. Ck. Coal No. 4	Loudon Twp., Kanawha Co., W. Virginia	662
W–8	United Fuel, Arrington No. 1	Clendenin Twp., Macon Co., W. Virginia	69
W–9	———	——— Pocahontas Co., W. Virginia	———
W–10	———	Union Twp., Preston Co., W. Virginia	———
W–11	———	Horton Twp., Randolph Co., W. Virginia	———
W–12	Hope Nat. Gas, Power Oil #9634	Walker Twp., Wood Co., W. Virginia	351

of the Estill, but in places thin dolomitic beds and siltstone are present. A widespread concentration of glauconite is characteristic of the basal part of the formation. In Highland and Adams Counties, the thickness of the formation ranges between 85 feet and 130 feet.

On the basis of conodont and brachiopod studies, most of the Estill is assigned a late Llandovery age (Rexroad, 1965, p. 24). The absence of Zone III conodonts and the presence of the ostracode *Mastigolbina typus* in the upper part of the formation suggest that this part of the Estill correlates with the middle portion of the Clinton Group of New York State.

Bisher Formation—The name Bisher was applied by Foerste (1917, p. 190) to the lower member of Orton's West Union Formation as exposed southeast of Hillsboro, Highland County, Ohio. The type locality is northeast of the Bisher dam site. In 1923 (p. 24), Foerste raised the Bisher to formational rank and abandoned the term West Union. The conformable contact between the Bisher and the underlying Estill Shale is sharp and distinct in most exposures, but the contact with the over-lying Lilley is gradational in many localities.

The most characteristic lithologic expression of the Bisher in southern Ohio, according to Bowman (1961, p. 265), is a silty, fine-grained, distinctly bedded dolomite, which tends to weather to a reddish-brown or buff color. The unweathered color varies from brown to gray. The Bisher has several lithofacies that result from changes in content of clay, silt, fine sand, and fauna. Dark-gray partly silty, dolomitic shale is present at some outcrops as partings or thin beds, but thicker exposures occur in a few places. Light-gray to bluish-gray dense limestone is present in parts of Highland County, and in some localities a medium- to coarse-grained bioclastic limestone is exposed. A thin persistent fossil zone dominated by the brachiopod *Cryptothyrella* [*Whitfieldella*] *cylindrica* occurs a few feet above the base of the Bisher in Highland and Adams Counties, Ohio (Rogers, 1936; Bowman, 1956). This zone provides an excellent reference bed for field studies. Recrystallization is common, producing a characteristic poikiloblastic texture. Insoluble residues show that quartz silt may comprise as much as 40 percent of some Bisher strata.

Bisher outcrops in Highland County, Ohio, range in thickness from 23 to 84 feet, according to Bowman (1961, p. 265). The Bisher is also exposed in Adams County, and across the Ohio River in Fleming and Estill Counties, Kentucky. Foerste (1931, p. 190) correlated exposures of the Bisher at Crooked Creek quarry, approximately four and one-half miles south of Sinking Springs, Adams County, Ohio, with the Rochester of New York State on the basis of ostracodes. Berry and Boucot (in press) indicate the Bisher is of Lower Wenlockian age.

Lilley Formation—The name Lilley was given by Foerste (1917, p. 190) to beds which Orton had previously designated the "Blue Cliff" stone. The name is taken from Lilley Hill at Hillsboro, Highland County, Ohio. Six years later, Foerste (1923, p. 42) raised the Lilley to formational rank. At the type locality, the Lilley is a gray finely crystalline, argillaceous dolomite, with some shale partings and a three-foot shale layer at the top. The Lilley lies conformably between the underlying Bisher Formation and the overlying Peebles Dolomite.

The most detailed study of the Lilley is that by Bowman (1956), who finds the greatest lithologic variation within the Niagaran of southern Ohio in the Lilley Formation. According to Bowman (1961), p. 266), the two most common lithologic types displayed by the Lilley are the crinoidal carbonate lithofacies and the argillaceous carbonate lithofacies.

The crinoidal carbonate is generally light-gray, medium- or coarse-grained, somewhat porous, weakly bedded or massive. It may be either limestone or dolomite. The rock is characterized by fossil fragments, mostly of crinoidal origin. This bioclastic phase may comprise the entire Lilley succession in a given locality. Where the outcropping Lilley strata are composed of more than one lithology, the crinoidal carbonate lithofacies occurs in the lower part of the formation, immediately above the Bisher.

The argillaceous carbonate lithofacies appears as an impure blue-gray, fine-grained dolomite, usually unevenly bedded, with or without shale. The shale is generally present as partings or thin interbeds, although a maximum thickness of 6 feet 8 inches has been measured in Highland County. The argillaceous carbonate beds become reddish when weathered and comprise the dominant lithofacies in Adams County. Bowman (1961, p. 266) states that, where several lithofacies constitute the Lilley in Highland County, the upper beds nearly everywhere show this argillaceous aspect.

The Lilley ranges in thickness from nearly 80 feet in northern Highland County to about 30 feet in southern Adams County. The thickening of the Lilley to the northwest, in the same direction as the Bisher thins, was explained by Bowman (1956, p. 47) as a displacement of the Bisher lithotope as the Lilley sea transgressed, resulting in lateral and vertical gradations between the two formations. According to Butterman (1961), residues from the Lilley may show variable amounts of silt or fine quartz sand and some local concentrations of limonite or chert. Bowman (1956, p. 72) believed the Lilley to be correlative with part of the Lockport of Ontario. Berry and Boucot (in press) find that the Lilley is correlative with all of the Rochester plus the uppermost Irondequoit and lowermost Lockport.

Peebles Dolomite—Foerste (1929, p. 168, 169) chose this name from the town of Peebles in northeastern Adams County, Ohio. The name was introduced as a substitute for Niagaran strata previously referred to as Guelph, Cedarville, or *Pentamerus* Limestone in the area around Hillsboro, Ohio. The Peebles is underlain conformably by the Lilley; according to Bowman (1961), this contact is transitional in Highland County, but becomes more distinct in Adams County. The Peebles lies unconformably beneath either the Greenfield Dolomite or, in some localities, the Ohio Shale. Where the Peebles underlies the Greenfield Dolomite in Highland County outcrops, a clayey deposit containing dolomite fragments occurs on the ancient Peebles surface (Bowman, 1956, p. 143).

The Peebles is generally 50 or 60 feet thick, but Bowman (1956, p. 109) measured approximately 89 feet of this formation a mile and a half west of "The Point", Paint Township, Highland County. The original pre-erosion thickness is unknown. Foerste (1935, p. 192) correlated the Peebles Formation with the Guelph strata of southern Ontario. Bowman (1956, p. 84) agreed with Foerste, declaring the Guelph and Peebles to be lithologically and faunally similar. Berry and Boucot (in press) indicate the Peebles is equivalent to nearly all of the New York Lockport.

Middle Silurian Strata in West Virginia

In West Virginia the Silurian units that occur at a stratigraphic position corresponding to the units in southern Ohio are:

McKenzie Formation
Rochester Formation
Keefer Sandstone
Rose Hill Formation

These units are described below.

Rose Hill Formation—This formation was named for exposures of shale above the Tuscarora Formation and below the Keefer Formation at Rose Hill, Cumberland, Maryland, by Swartz (1923, p. 280). In West Virginia, Woodward (1941) divided the formation into: 1) an upper fossiliferous part containing some thin limestone beds, which are the only carbonates in the Rose Hill outcrops, 2) a middle part containing mostly olive-green shale with sparse fossils, and 3) a lower part consisting of moderately fossiliferous predominantly greenish shale.

The majority of the Rose Hill exposures consist of olive-colored clay shale, with lesser amounts of purplish shale. Thin siltstone or fine sandstone layers are interspersed throughout the formation and in certain areas deep-red hematite-cemented quartz sandstones occur. Additional ironstones of this type are interbedded with shale between Botetourt, Virginia, and Monroe County in southern West Virginia. These red sandstones were named the Cacapon facies by Butts in 1940. Thin beds of oolitic or fossiliferous hematite were once economically valuable and were mined in parts of New York, Virginia, and central Pennsylvania. Equivalent Clinton hematite beds are still mined near Birmingham, Alabama.

According to Woodward (1941), the thickness of the Rose Hill in central Pennsylvania is 800 feet. Southward along the outcrop, the thickness of the

Rose Hill strata decreases to 600 feet in western Maryland and eventually thins to 400 feet in southwestern West Virginia. The formation also thins in the subsurface as it is traced westward into Ohio. The Rose Hill fauna, consisting chiefly of ostracods, supports a correlation with the lower part of the Clinton Group of western New York State, according to Swartz (1934, 1942).

Keefer Sandstone—The Keefer Sandstone was named and defined by Ulrich in 1911 as the basal member of the McKenzie Formation. The type locality is at Keefer Mountain near Hancock, Maryland. Woodward (1941) elevated the Keefer to the rank of formation in West Virginia. It overlies the Rose Hill Formation and underlies the Rochester Formation in northeastern West Virginia. In the southern and western portions of West Virginia, dolomite beds of the McKenzie overlie the Keefer strata.

Folk (1960), Woodward (1941), and Swartz (1923) state that the Keefer Sandstone has two facies. In central Pennsylvania and in the western Silurian outcrop belt of West Virginia, the Keefer Sandstone is calcite-cemented, partly friable, and contains thin fossiliferous limestones. In many places a thin oolitic bed of hematite occurs at the top of the formation. In southeastern Pennsylvania and in the eastern Silurian outcrop belt of West Virginia, this predominantly sandstone formation is well cemented by silica, lacks limestone or hematite beds, and is unfossiliferous.

The presence of thick beds of sandstone in Mercer County, West Virginia, and in south-central Virginia suggests that a source area for the Keefer existed in that direction. Patchen (1968) indicated that the lower 50 or 60 feet of the 150 to 250 feet of sandstone in Mercer County appear to be Keefer. Woodward (1941) reported the Keefer to average 25 feet in thickness along the West Virginia outcrop. Westward the formation thins to about 10 feet in the subsurface of some parts of western West Virginia and, according to Rittenhouse (1949), wedges out along the Ohio-West Virginia line.

Rochester Formation—James Hall (1838) gave the name Rochester to strata exposed along the Genessee River at Rochester, New York. Woodward (1941) indicated that the Rochester formed the upper part of the Clinton Group in West Virginia. He described these strata as thin-bedded, fissile or platy, gray to dark shales, containing some beds of dense fossiliferous blue-gray limestone.

Rochester outcrops are present in the northeastern counties of West Virginia, but the Rochester is absent in the southern part of the state. Exposed Rochester strata average about 25 feet in thickness at outcrops in northeastern West Virginia and conformably overlie the Keefer Sandstone. According to Hunter (1960, p. 193), the Rochester Shale grades eastward from outcrops in Pennsylvania and New York into the Keefer and Herkimer Sandstones, which are directly overlain by the McKenzie or Lockport Formations. Swartz (1935) has suggested the presence of a hiatus, because of the distinct faunal change between the Rochester and overlying McKenzie, but Hunter (1960, p. 193) says that the lithologic change is transitional throughout much of the Central Appalachian Basin. Where basal limestone and shale beds of the McKenzie resemble the Rochester strata, the upper contact of the Rochester is chosen with the aid of paleontological evidence.

McKenzie Formation—The name McKenzie was derived from Pinto-McKenzie station on the Baltimore and Ohio Railroad, nine miles south of Cumberland, Maryland. This name was applied to the interbedded shale and limestone exposed there, which were first described by Stose in 1912. However Ulrich had introduced the name a year earlier (1911) in his *Revision of the Paleozoic Systems.* The McKenzie is underlain by the Rochester in Maryland and northern West Virginia, and by the Keefer Sandstone in southern West Virginia. In its outcrop in eastern West Virginia, the McKenzie is overlain by the Williamsport Sandstone, but the Williamsport thins in the western part of the state, and is locally absent, at which places the Wills Creek Formation overlies the McKenzie.

The McKenzie Formation consists mostly of dark gray to olive, partly calcareous, fissile to platy shale, with thin interbeds of gray limestone. Ostracodes are abundant in the limestone. Travis (1962, p. viii) notes the presence of some interbedded siltstone and sandstone at outcrops in West Virginia. Dolomite beds, which occur in the subsurface, increase in number as the formation is traced

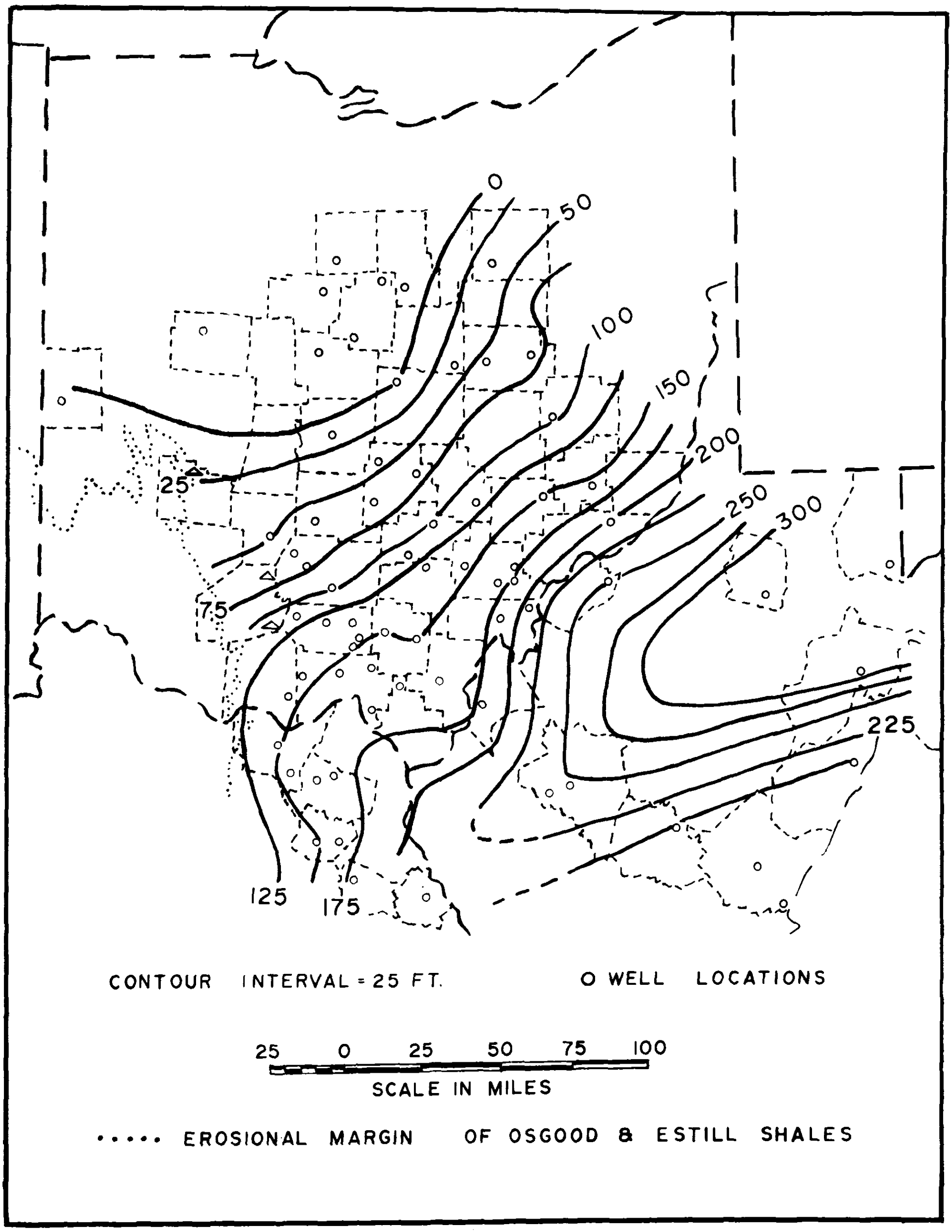

FIGURE 3. Isopach map showing erosional margin (post-Silurian) and thickness of Estill (Osgood) Shale.

westward toward the Ohio border. Travis (1962 p. viii) states that shale, siltstone, and thin limestone predominate in northeastern West Virginia, and that limestone and sandstone are more abundant to the south and southeast. Travis (1962, p. ix) recognized four lithological subdivisions of the McKenzie cropping out in western Maryland and eastern West Virginia, which, although not everywhere present, are:

4. Arenaceous shale and interbedded limestone, including some redbeds in easternmost exposures.
3. Upper calcareous shale and limestone.
2. Sandstone.
1. Lower calcareous shale and argillaceous limestone.

The McKenzie is exposed along the outcrop from central Pennsylvania to east-central West Virginia, where, south of Greenbrier County, it appears to be replaced by terrigenous equivalents. The formation is 350 feet thick at the north end of an axis extending from south-central Pennsylvania through westernmost Maryland into Pocohontas County, West Virginia. Near Huntersville in Pocohontas County, the thickness decreases to 150 feet. In the subsurface of western West Virginia, the McKenzie beds intertongue with the Lockport Dolomite, according to Travis (1962). In 1935, F. M. Swartz advocated a correlation with the Lockport of New York state, after a thorough study of the McKenzie led to the conclusion that environmental differences caused the absence of typical Lockport fauna from the McKenzie beds.

"Clinton shale"—The name Clinton Group was applied by T. A. Conrad in 1839 to beds underlying the Niagara Shale (Rochester Shale) and overlying the Niagara Sandstone (Albion Sandstone). The application of the names Clinton Group or Clinton Formation to beds between the Rochester Shale and the Albion Sandstone was universally followed until the early 1900's, when a series of changes were proposed.

The upper limit of the Clinton Formation was not defined in the original description. J. M. Clarke (1910) wrote that it might be unwise to separate the Rochester and its fauna from the series (Clinton) with which it was so intimately bound in the type section. Some proposals included and others excluded the Rochester from the Clinton. In a 1923 redefinition by Ulrich (Swartz, 1923, p. 244, 267), the Thorold Sandstone (member of the Albion) was included at the base and the Rochester was accepted as the top member of the Clinton Formation. Also in 1923, C. K. Swartz introduced the term Rose Hill Formation for the pre-Rochester part of the Clinton Group in Maryland. Woodward (1941) wrote that the Clinton Group of West Virginia comprises, in ascending order, the Rose Hill Formation, the Keefer Sandstone, and the Rochester Shale. The Clinton Formation as presently defined by the U. S. Geological Survey includes the same stratigraphic section included by Woodward in the Clinton Group of West Virginia.

The term "Clinton shale" has been applied by some drillers and geologists to shaly strata underlying the Lockport and overlying the Little Shell (Dayton Formation) in the Ohio subsurface. In practice, this name has not been used for the same stratigraphic units in central and in southern Ohio. In central Ohio, the Estill Shale forms the lower part, siltstone and silty Bisher carbonates form the thin middle part, and the dolomitic shale lithofacies of the Bisher forms the upper part of the "Clinton shale" (drill hole O–13, lower cross-section, fig. 5). In southern Ohio, where the silty carbonate lithofacies of the Bisher predominates, with relatively minor amounts of dolomitic shale and other lithofacies, the entire Bisher is commonly included with overlying Lockport strata in drilling reports; in this area, the "Clinton shale" of the driller refers essentially to the Estill Shale.

SUBSURFACE INVESTIGATION

The release of the Attinger and Miller cores (fig. 1; Table 1, O–40 and O–39,

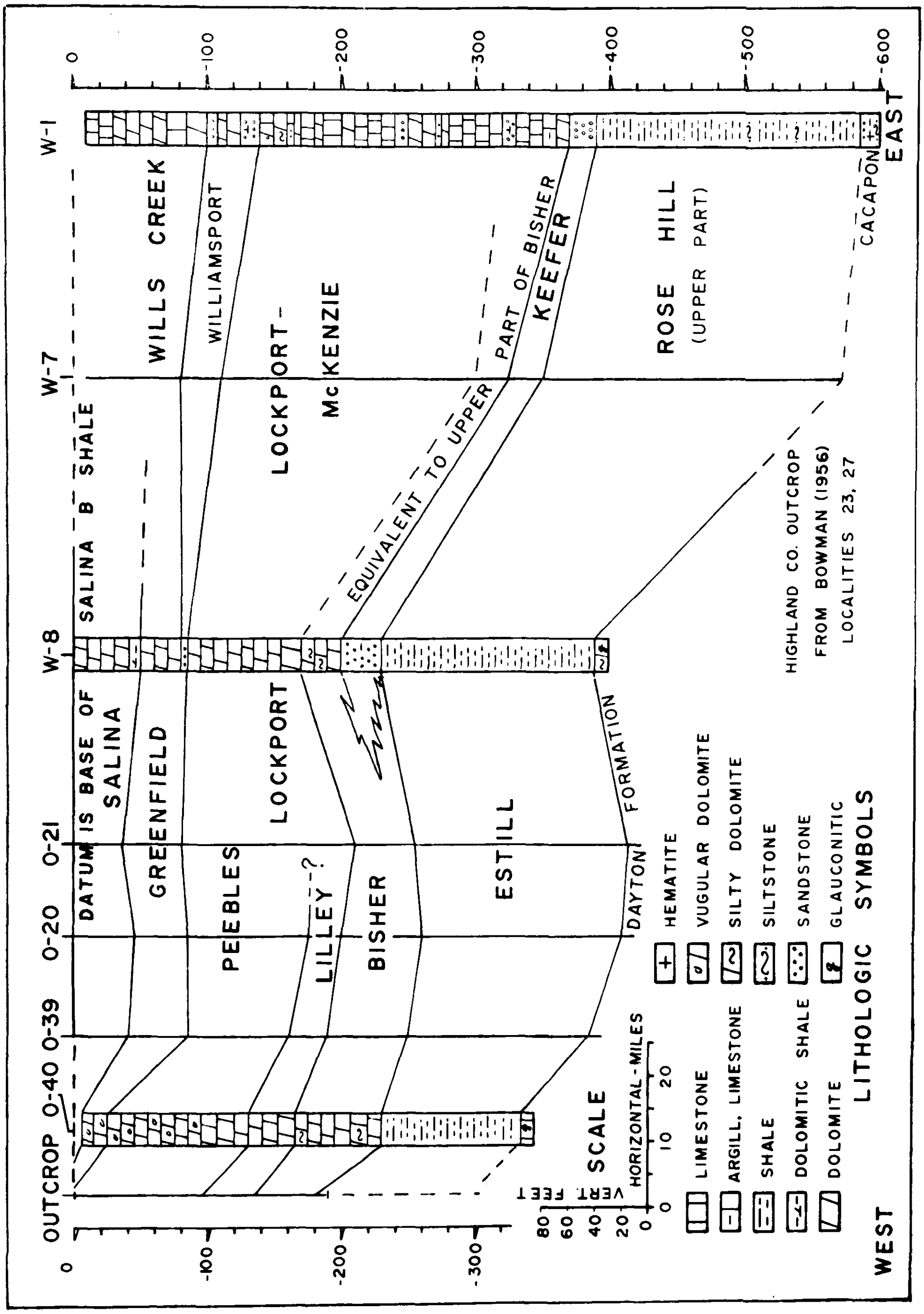

FIGURE 4. Cross-section C–D from eastern Highland County, Ohio to northern Fayette County, West Virginia; located on fig. 2.

respectively) by the Continental Oil Company in 1962 facilitated the task of tracing the Silurian units exposed in Highland and Adams Counties, Ohio, into the subsurface. Successive core segments were compared to rock chips from nearby Highland County outcrops with respect to the lithology and thickness of the rock units, and their stratigraphic sequence. Variations in color, grain size, bedding characteristics, silt content, and presence of weathered surfaces aided identification of the Silurian units in the cores. The footage depths of the formation contacts in the cores were transferred to the corresponding positions on the gamma-ray neutron logs of the core holes. Similar formation contacts were picked in nearby drill holes with the aid of both drill cuttings and gamma-ray neutron logs of these holes. The subtle changes in lithology recorded by this sensitive radiation-logging procedure was checked against the lithologic evidence provided by the drill cuttings. By this procedure, the rock units were traced from outcrops in Highland County to the Miller and Attinger core holes in Pike County, then to nearby drill holes in adjacent counties, and finally to a total of 76 drill holes in Ohio, Kentucky, and West Virginia.

All of the middle Silurian units that crop out in southwestern Ohio were traced into the subsurface, although some units could be traced for longer distances than others, because of their persistent and distinctive lithology. Details of the information obtained from the study of these 76 drill holes are presented below.

Estill Shale

The Estill is a "blue" shale near the type locality in Kentucky, and, at surface exposures in southwestern Ohio, it is a greenish-gray clay shale containing dolomite stringers. In the Ohio subsurface, the color changes from gray or grayish-green near the top to a mixture of brown, maroon, and grayish-green throughout the lower part of the formation. Thin interbeds of dolomite and dolomitic silt-stone occur in the Ohio and Kentucky subsurface. The presence of thin siltstones and thin carbonate beds containing silt was noted by Kaufmann (1964, p. 107) within the upper 30 or 40 feet of the Estill Shale at a number of outcrops in Adams County, Ohio. The basal glauconite zone described by Rexroad and others (1965, p. 24) continues into the subsurface and has been traced throughout most of southern Ohio.

A probable equivalent of the Estill, in Greene, Preble, and surrounding counties northwest of the Highland County, Ohio, outcrop, is the Osgood Shale. This conclusion is supported by the similarities in lithology, stratigraphic position, and apparent subsurface continuity of these two formations.

The isopach map (fig. 3) of the Estill shows the formation thinning as it is traced from southeastern Ohio through central Ohio in a northwesterly direction. The isopach contours which show a thickness of 175 feet or more are approximations of the thickness of the Estill based on projections of the Dayton-Estill contact. This approximation is also shown on the east-west cross section (fig. 4), where the Estill Shale is shown thickening eastward from the Highland County, Ohio, outcrop, and then merging with the upper part of the Rose Hill Formation in the subsurface of West Virginia (drill holes W-1 & W-7 on fig. 2 and fig. 4). On the cross section, a dashed line is used to designate the estimated Dayton-Estill contact, which occurs somewhere in the middle of the Rose Hill strata. Estill thicknesses are imprecise for most of West Virginia, because of facies changes that occur in the Dayton beds as they are traced eastward. However in the W-12 drill hole in Wood County, West Virginia (fig. 2), slightly glauconitic medium-crystalline dolomite containing some silt was identified as Dayton. Drill cuttings from this hole indicate a thickness of 255 feet of Estill Shale. The Estill Shale and part of the overlying Silurian section for the W-12 drill hole are recorded below.

W-12 Section. Partial lithologic log of the Hope Natural Gas Co. drill hole, No. 9634, Wood County, West Virginia. Elev. 1050 ft.

Depth below Surface	Unit	Thickness in feet
	Silurian	
7015 ft.	Lockport Dolomite	200
	8. Light to medium brown, fine- and medium-crystalline dolomite; some oolites; upper part has Greenfield aspect........45	
	7. Dark brownish-gray, fine-grained, argillaceous dolomite..... 8	
	6. Medium- and dark-brown, very fine- to medium-crystalline limestone; partly argillaceous........40	
	5. Light- to dark-brown, fine- and medium-crystalline limestone; lower 10 ft. dolomitic; brachiopods at 7110–20........47	
	4. Dark grayish-brown, medium-crystalline limestone; residues of fine quartz silt, argillaceous matter, and pyrite........40	
	3. Grayish-brown, arenaceous limestone; contains subangular to subrounded quartz. Units 3 & 4 may be Bisher equivalents..20	
7215	Keefer Sandstone	35
	2. Light-gray siltstone and fine-grained sandstone; cement is slightly dolomite or calcareous........35	
7250	Estill Shale (upper part of Rose Hill Formation)	255
	1. Gray, reddish-gray, and greenish-gray shale; unit containing numerous thin interbeds of siltstone and fine sandstone; slightly glauconitic near base of unit........255	
7505	Dayton Formation	

A comparison of units 1 and 2 in the above description shows the abrupt change in lithology from the Estill Shale to the overlying Keefer Sandstone. Unit 2, and probably units 3 and 4, can be traced westward into the Bisher Formation, which crops out in Highland and Adams Counties, Ohio (fig. 1). Sand and silt grains, which form the Keefer Sandstone in West Virginia, decrease in quantity northwestward into Ohio and provide the quartz content in the distinctive silty and sandy carbonate facies of the Bisher.

Bisher Formation

The generally fine-grained appearance of the Bisher carbonates, the characteristic poikiloblastic texture, and the residues of fine quartz sand or silt are useful in identifying this formation at outcrops and in the subsurface. The quartz residue shows up when small surface samples or drill cuttings are treated with acid. Bisher strata in southern Ohio almost invariably show a silty carbonate aspect in the upper, as well as in the basal, part of the formation, overlying the Estill Shale. Commonly the upper part of the formation has less quartz residue than does the basal part. Other Bisher lithofacies may occur between the silty carbonate beds. Where the overlying Lilley is non-argillaceous, the contact between the two formations is gradational and not easily determined. Along a west-east cross-sectional line from Pike County, Ohio (O-40), to Mason County, West Virginia (W-8), where the top of the Bisher contains silt (fig. 4), the Bisher-Lilley contact is placed at the upper limit of carbonate beds having a significant residue of fine quartz sand or silt.

In Fairfield and Licking Counties (drill holes O-13 and O-24 respectively), and on to the north, the quartz residue is less or absent, and in the two counties cited, the Bisher strata are more argillaceous than in counties to the south. The dolomitic shale lithofacies comprises a larger portion of the Bisher in Fairfield and Licking Counties than it does in Highland County, although Bowman (1956, p. 41) measured an unusual thickness (exceeding 15 feet) of dolomitic shale in one Highland County locality. The following description of the Bisher from a drill hole log in Fairfield County indicates the characteristic Bisher lithology for this part of central Ohio.

0–13 Section. Partial lithologic log of the Graber, Fisher No. 1 drill hole, Violet Township, Fairfield County, Ohio. Elevation not available.

Depth below Surface	Unit	Thickness in feet
	Silurian	
1165 ft.	Lockport Dolomite	45
	6. Pale-brown, fine- to medium-crystalline, porous dolomite; trace of fine quartz silt in 1180–93 interval.....45	
1210	Bisher Formation	60
	5. Tan and light-brown, fine-grained, dense dolomite; slight amount of pyrite and quartz silt.....10	
	4. Brown dolomitic and calcareous shale; minor pyrite and quartz silt.....30	
	3. Brown, finely crystalline to buff medium-crystalline limestone; partly silty and crinoidal..... 9	
	2. Gray argillaceous, dolomitic silstone, with some gray silty shale.....11	
1270	Estill Shale	55
	1. Brown soft shale predominant; some glauconitic green shale near the base.....55	
1325	Dayton Formation	

"Clinton Shale"

In the preceding log of drill hole O–13, units 1 through 4 comprise the "Clinton shale"; unit 1 makes up the lower part of the "Clinton shale", units 2 and 3 comprise the middle part, and unit 4 forms the upper part of the "Clinton shale". The lower cross-section on figure 5 shows the three-fold division of the "Clinton shale" for the sections penetrated by the O–13 and two other drill holes, and the upper cross-section utilizes lithologic symbols to show a clearer picture of the facies changes between these same drill holes. The somewhat-deeper-water Estill clay shales grade northwestward from the vicinity of the O–13 drill hole into dolomitic shales, and farther along near the O–30 drill hole in Morrow County, the dolomitic shales grade into partly argillaceous carbonates. Part of the Bisher apparently was deposited as a shallow-water facies of the Estill; as the source of the Estill Shale became depleted and the central Ohio portion of the basin became shallower, the Bisher lithotope shifted southeastward, depositing argillaceous carbonates on top of the Estill Shale. On the lower cross-section (fig. 5), the gamma-ray curves show progressive thinning, between drill holes O–13 and O–30, for each of the three parts of the "Clinton shale". The thinning of vertically successive units, combined with the change in facies (already discussed), suggests that the O-line on the isopach map of the Estill Shale (fig. 3) represents the depositional limits of the shale rather than an erosional unconformity.

This three-fold division of the "Clinton shale" is also developed to the east of Fairfield and Licking Counties in Coshocton, Muskingum, and Knox Counties, where concentrations of quartz increase in the middle part of the "Clinton shale". In these counties, the middle part of the "Clinton shale" more nearly resembles the Keefer than the typical silty or arenaceous carbonate lithofacies of the Bisher. The upper part of the "Clinton shale" possesses alternating lithologies of silty, argillaceous dolomite and silty dolomitic shale having Bisher affinities; most of the lower part of the "Clinton shale" is composed of beds identifiable as Estill Shale.

The writer concludes that the term "Clinton shale" is commonly applied to a combination of three units in central Ohio: 1) clay shale (Estill), 2) silty carbonates and siltstone (Keefer-Bisher), and 3) dolomitic shale and argillaceous carbonates (Bisher). This usage differs from the application of the term "Clinton shale" in southern Ohio to a single unit, the Estill Shale.

Lilley Formation

The Lilley is the most difficult of the formations described in this report to

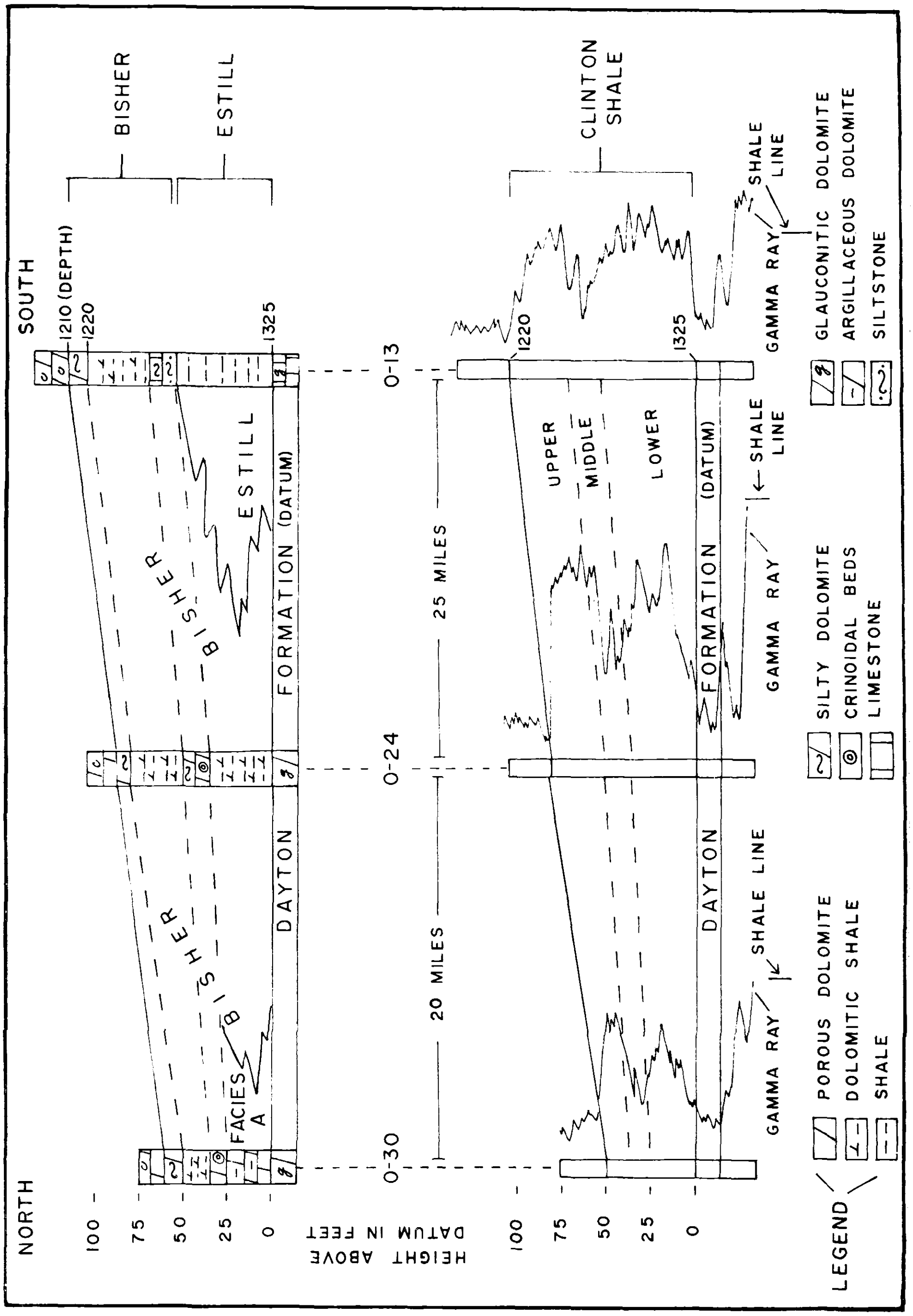

FIGURE 5. Cross-section E–F in central Ohio showing facies relationship between various parts of the "Clinton shale"; located on fig. 2.

trace in the subsurface. Bowman (1961, p. 266) writes that the greatest lithologic variation within the Niagaran of southern Ohio occurs in the Lilley Formation. Some of the diagnostic characteristics of this unit, such as the weathered condition of the beds at outcrop are not present in drill cuttings. Nevertheless, the Lilley can be traced into the subsurface of Pike and parts of adjoining counties to the east of Highland County (figs. 4 and 6). The gray argillaceous carbonate lithofacies of the Lilley can readily be identified in drill cuttings. The argillaceous character of these beds also produces slight fluctuations in the gamma-ray neutron

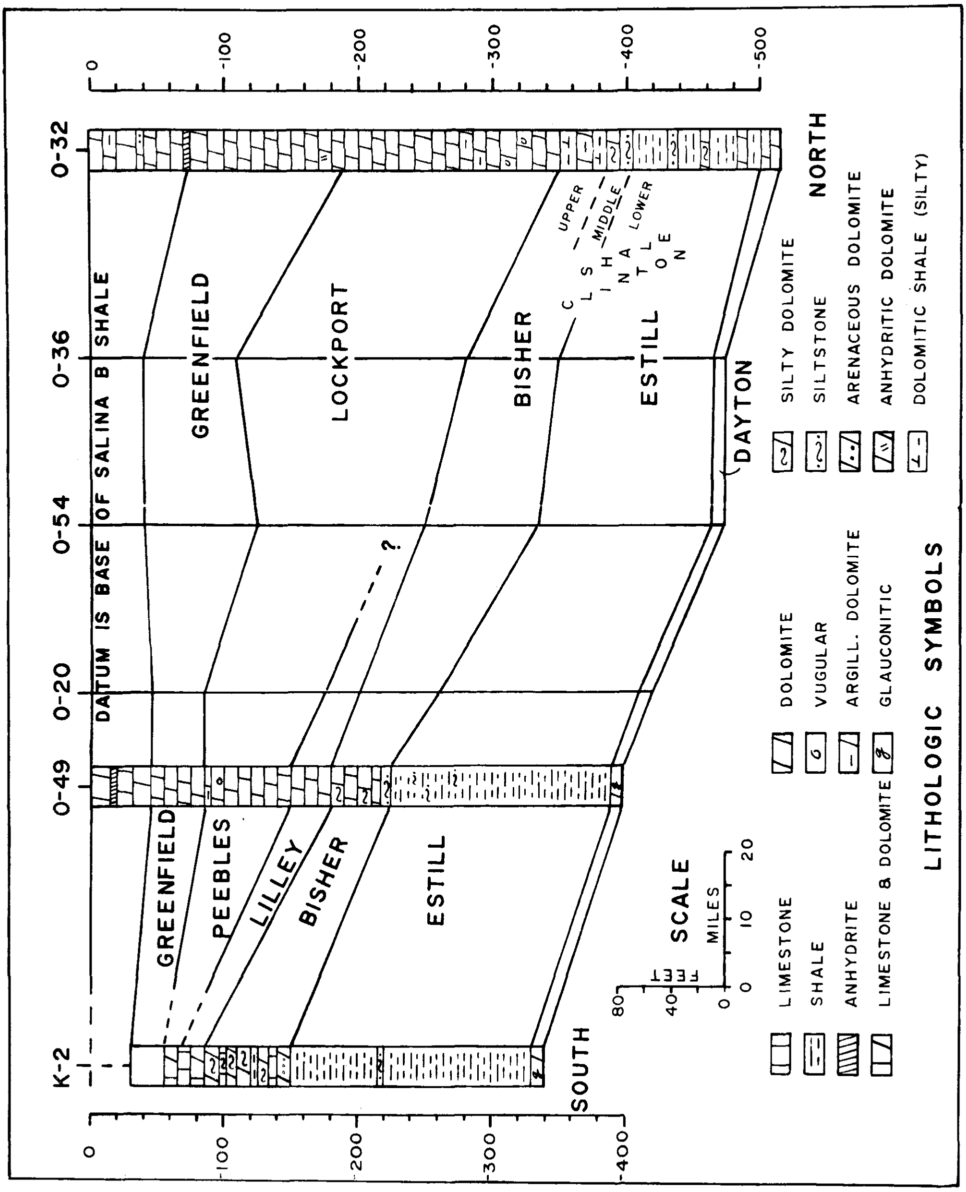

FIGURE 6. Cross-section A–B from western Carter County, Kentucky to northeastern Muskingum County, Ohio; located on fig. 2.

curves (fig. 7). Bowman's (1961) field observations that, where several lithofacies comprise the Lilley, the upper beds are nearly everywhere argillaceous, appear to be valid for subsurface localities a few miles east of Highland County, Ohio. Where the argillaceous Lilley underlies the Peebles, the contact between the two can be selected with reasonable certitude.

The Lilley conformably overlies the Bisher and underlies the Peebles Dolomite. Peebles-Lilley interbedding was noted by Bowman (1956, p. 96, 111) at some localities in Highland County. A similar transition zone occurs in some subsurface localities. Eastward from Highland and Adams Counties, Ohio, drill cuttings in some localities show that basal Lilley beds contain increased amounts of quartz silt, which tend to obscure the lower contact with the Bisher.

Three Lilley lithofacies are indicated by cuttings from the Wenzel drill hole (O–45, fig. 1) in Ross County, Ohio: 1) dolomitic shale, 2) crinoidal carbonate, and 3) argillaceous carbonate. The latter two lithofacies apparently are also present in the Anderson (O–41), Grover (O–20), and Dever (O–49) drill holes (table 1; fig. 1) in Pike, Jackson, and Scioto Counties, respectively. The Dever and Grover drill holes are also shown on the south-north cross-section (fig. 6). North of Ross County, the Lilley could not be positively identified. The Lilley is traceable in the subsurface east of Pike County to the middle of Jackson County, Ohio. Farther east in that part of the Appalachian Basin, near the Ohio-West Virginia border, beds equivalent to the Lilley probably occur near the base of the Lockport or McKenzie Formations. The McKenzie Formation of West Virginia was traced into the Lockport beds of the eastern Ohio subsurface by Travis (1962), who noted an intertonguing relationship.

Data from the southern Ohio drill holes in which the Lilley can be identified indicate that the formation ranges between 30 and 80 feet in thickness. The relatively few drill holes where the Lilley could be accurately measured did not show a regional pattern of regular thickening in a preferred direction. The fact that some Bisher beds in the subsurface contain abundant crinoids, together with the observation by Bowman (1961, p. 266) that upper Bisher strata pass laterally into the crinoidal carbonate lithofacies of the Lilley to the north and west in Highland County, support Bowman's conclusion that parts of the Lilley and Bisher were deposited simultaneously.

Peebles Dolomite

The Peebles Dolomite can be recognized in cuttings from the subsurface of Pike County, Ohio, only a few miles east of an outcrop described by Bowman (1956, p. 109, loc. 23). Drill cuttings indicate that the Peebles consists of light-gray to grayish-brown, fine- and medium-crystalline dolomite. A porous zone is sometimes present in the upper part of the formation and has been referred to by drillers as the Newburg zone. In other regions, the term Newburg has been applied to slightly different stratigraphic intervals; in some Ohio areas, the term Newburg refers to porous beds in the basal part of the overlying Greenfield Formation. In West Virginia, the Williamsport Sandstone forms the Newburg zone Patchen, (1968). Bowman (1961, p. 267) noted the presence of clay and soft, friable, weathered dolomite in the uppermost part of the Peebles beds in Highland County. Evidence of this disconformable upper contact of the Peebles occurs in the two cores and in a few drill holes. The lithologic log for one of these cores is given below.

0–40 Section. Partial lithologic log of the Continental Oil Company, Attinger No. 1 drill hole, Perry Township, Pike County, Ohio. Elevation: 930 feet.

Depth below Surface	Unit	Thickness in feet
	Silurian	
155 ft.	Peebles Dolomite	107.5
	12. Pale-brown, fine-crystalline, vesicular dolomite; bituminous	

	matter in some vesicles; a 1-inch weathered zone at top shows iron-oxide stain . . . 13	
	11. Gray and brownish-gray, mottled fine-crystalline dolomite; moderately vesicular . . . 40	
	10. Buff and pale-brown, fine-crystalline dense dolomite; some small vesicles from 217 to 218 and 225 to 232 ft.; *Fletchereria* sp. at 246 ft . . . 50	
	9. Gray and brownish-gray dolomite; contains pale-brown calcareous colonial corals . . . 4.5	
	Lilley Formation . . .	31.5
	8. Predominantly gray, fine-crystalline argillaceous, dense dolomite; colonial corals; lower 4 feet is medium-crystalline and contains crinoids, brachiopods, and coral *Coenites* sp . . . 13.5	
	7. Gray and brownish-gray, predominantly fine-crystalline dolomite; moderately argillaceous; chert at 281 and 286 ft., coral fragments at 292 and 294 feet . . . 18.0	
294	Bisher Formation . . .	68.5
	6. Pale-brown and gray fine-crystalline, dolomite; silty and partly argillaceous; poikiloblastic texture at 299 ft.; concentration of quartz silt at 301 ft . . . 17.0	
	5. Grayish-brown, fine-crystalline, calcareous dolomite; scattered chert; crinoid stems at 317 and 325 ft . . . 23.0	
	4. Pale-brown to brownish-gray, fine-crystalline dolomite and limestone . . . 4.0	
	3. Brown and brownish-gray dolomite; fine-crystalline, argillaceous; lower 6 inches is medium- and coarse-crystalline limestone containing brachiopods . . . 27.5	
	2. Pale-brown, fine- and medium-crystalline calcareous dolomite; contains quartz silt; abundant crinoid columnals 2 ft below top of unit . . . 7.0	
362.5	Estill Shale . . .	103.3
	1. Greenish-gray and maroon shale; thin interbeds of ½- to ¼-inch limestone layers . . . 103.3	
465.8	Dayton Formation	

The clay at the Peebles-Greenfield contact was also detected in cuttings from the Ross County drill hole O–45 (fig. 1), but in other drill holes the presence of the clay and weathered surface is inferred only from a fluctuation on the gamma-ray neutron log.

Northward from Pike County, the Peebles was traced as far as Morrow County, Ohio (drill hole O–30). North of this locality, in northern Ohio, the relationship of reef carbonates and other Lockport facies to the Peebles Dolomite is still uncertain. Pounder (1963), along with other investigators, recognized a three-fold division of the Lockport in the Ontario subsurface. Preliminary studies show that this same three-fold division is recognizable in Richland County and other northern Ohio counties (Horvath, 1964, p. 84).

Southward from Pike County, Ohio, drill cuttings show that the Peebles is present in Lewis County, Kentucky (drill hole K–7). The formation has been reported by McFarlan (1943, p. 314) as being present in the subsurface of Estill County, Kentucky.

The lithology, faunal content, and thickness of the Lockport Dolomite in western Ohio have been interpreted by Travis (1962), Alling and Briggs (1961), and others as indicative of reef build-up. A non-uniform pattern of regional thickening and thinning, plus the faunal content and purity of the Peebles, suggest that these carbonates originated under reef-bank or related conditions. Commonly the Peebles is 40 to 50 feet thick in Highland County outcrops, although Bowman (1961, p. 267) estimated a maximum thickness of over 100 feet there. A few miles to the east, in western Pike County, 107 feet of this formation is present in the subsurface (drill hole O–40). In eastern Pike County, the Peebles is 85 feet thick, and in Ross and Pickaway Counties, the writer noted thicknesses of 125 and 50 feet, respectively, at drill holes O–45 and O–37.

Some evidence of the clay at the top of the Peebles exists as far eastward as

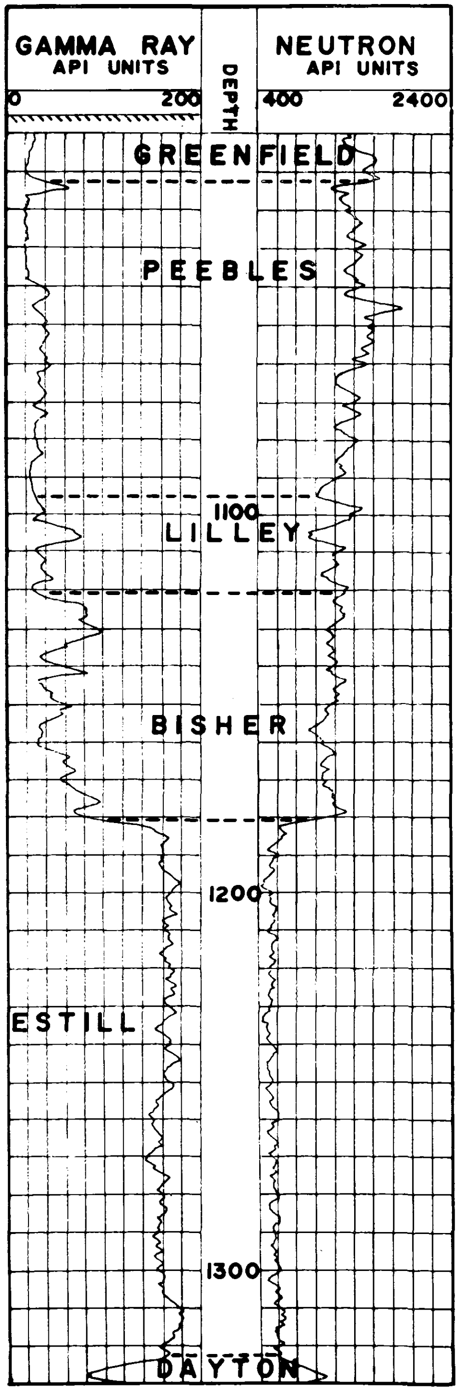

FIGURE 7. Portion of gamma-ray neutron log for drill hole 0-41, Seal Township, Pike County, Ohio.

western Jackson County, although definite indications of subaerial weathering were found only in the clayey, porous, oxidized core fragments described in the lithologic log for the Attinger (O-40) core hole on a preceding page. Figures 1 and 2 show the location of this strategic core hole in western Pike County. East of western Jackson County, there is no indication of an unconformity between the Greenfield and the Peebles. The Peebles Dolomite thins as it is traced eastward; slightly greater thicknesses of this formation occur in the shelf area flanking the Cincinnati Arch in southwestern Ohio.

TABLE 2

Subsurface data from drill holes shown on figures 6 and 4
(Depth of rock units below surface in feet)

A. West-east cross section

Number	Elevation	Greenfield	Peebles	Lockport-McKenzie	Lilley	Bisher	Keefer Big-6	Estill	Dayton
O-40	939	135	155	—	260	295	—	360	465
O-39	681	580	625	—	698	728	—	790	926
O-20	959	1685	1725	—	1815	1840	—	1900	2050
O-21	765	2450	2540	—	—	2625	—	2670	2830
W-8	597	3990	—	4025	—	4110	4140	4170	4420
W-7	984	—	—	5560	—	5750	5775	5800	—
W-1	2150	—	—	7840	—	8020?	8070	8090	—

B. South-north cross section

Number	Elevation	Greenfield	Peebles	Lockport-McKenzie	Lilley	Bisher	Keefer Big-6	Estill	Dayton
K-2	846	1335	—	1360	—	1390	1445	1455	1635
O-49	585	1540	1580	—	1645	1675	—	1720	1885
O-20	959	1685	1725	—	1815	1840	—	1900	2050
O-54	971	2260	—	2325	—	2450	—	2535	2665
O-36	970	3115	—	3186	—	3384	—	3423	3540
O-32	1012	3940	—	4055	—	4210	—	4255	4360

SUMMARY OF SUBSURFACE INVESTIGATIONS

Clays belonging to the Estill Shale and Osgood Formation originally covered Ohio south and east of the O-contour on the isopach map (fig. 3); to the northwest of this O-contour line, a thin carbonate facies was deposited in the shelf area flanking the Findlay Arch. Traces of the glauconitic shale zone found near the base of Estill appear in outcrops in Adams County, Ohio, and persist eastward in the subsurface to the Ohio-West Virginia border. In the subsurface of Mason and Wood Counties, West Virginia (drill holes, W-8 & W-12, respectively; fig. 2), the Estill is continuous with the upper part of the Rose Hill Formation, overlying the Dayton Formation or its equivalent.

In southwestern and south-central Ohio, and in parts of northern Kentucky (fig. 6), the Estill is overlain by Bisher carbonates and underlain by Dayton strata; in this area, the Estill is sometimes listed as the "Clinton shale" in drilling reports. In the subsurface of central Ohio, the Estill forms only the lower part of what is referred to as the "Clinton shale"; the middle part of the "Clinton shale" there consists of silty carbonates or calcareous siltstones possessing characteristics intermediate between those of the Keefer Sandstone and of the silty carbonate lithofacies of the Bisher; the upper part of the "Clinton shale" is dolomitic shale or argillaceous carbonate beds that resemble the dolomitic shale lithofacies of the Bisher. The argillaceous material may have come from the same source region that contributed dark, organic-rich muds to the Rochester lagoon in Morgan County, West Virginia (Folk, 1962).

The argillaceous matter contained in the Bisher apparently was brought into Ohio from the northeastern and eastern parts of the Appalachian Basin; at the same time a source of coarser clastics existed in the southeastern part of the Appalachian Basin. While the Keefer sands accumulated in West Virginia, currents swept some of the sand and silt westward to form the silty Bisher carbonates of eastern and southern Ohio. In Licking and Fairfield Counties, Ohio (fig. 2), an argillaceous, less silty Bisher was deposited. Increased distance from the source of the quartz grains or a possible trapping by the intervening deeper current-less part of the basin may have caused this change in composition. Folk (1962) states that, for a short interval, it is likely that Rochester, Keefer, and Rose Hill sediments were accumulating in different parts of the (W. Virginia) basin at the same time; in Ohio, parts of Estill, Bisher, and nearby shelf carbonates (facies A, fig. 5) were probably being deposited synchronously with the West Virginia sediments.

The several lithofacies of the Lilley indicate a continuation of the varying environmental conditions that influenced Bisher sedimentation. By the end of Lilley time, the periodic pulsations of clastic influx from eastern sources gradually weakened and the seas cleared sufficiently to produce the pure biogenic carbonates that characterize the Peebles.

The Lilley Formation was traced eastward, northeastward, and southward about 40 miles (figs. 4 & 6) in the subsurface; lithologic characteristics of the Peebles persisted for somewhat greater distances. Intertonguing beds of Lockport dolomite and McKenzie limestone, occurring in the subsurface of eastern Ohio and western West Virginia (Travis, 1962), are probable facies equivalents of the Peebles and Lilley Formations.

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